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Autonomic nervous system of the pelvis — general overview

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Abstract: Autonomic nervous system of the pelvis is still poorly understood. Every year more and more pelvic procedures are carried out on patients suffering from different pelvic disorders what leads to numerous pelvic dysfunctions. Authors tried to review, starting from historical and clinical background, the most important reports on anatomy of the pelvic autonomic plexuses. We also pay attention to complete lack of knowledge of students of medicine on the autonomic nervous structures in the area studied. We present anatomical description of the pelvic plexuses including their visceral branches and anatomy of surrounding pelvic tissues which still remains unclear. More and more attention is paid to the topography of the plexuses specially because of new pain releasing techniques — neurolysies.

Key words: autonomic nervous system, inferior hypogastric plexus, anatomy, nerve sparing, pelvis.

Introduction

The innervation of human pelvis was a subject of numerous studies and reports of the scientists who studied both fresh and embalmed cadavers (Hunter, Lee, Beck, Frankenhäuser, Davis, Labate, Krantz, Quinn). Despite the studies conducted so long, there information on the structure, course, and the range of innervation of the hypogastric plexuses still remains scanty. Poor understanding of the innervation of pelvis viscera is also a result of poor emphasis of teaching about the structures of the nervous system during anatomical academic studies. Delicate nerves, often small caliber, become more vulnerable under the influence of formalin, especially during dissection. These technical and substantive difficulties lead to one result: among the scientist, students, even practicing physicians there is still not too much attention paid to clinical importance of these nervous structures.

Historical overview includes reports of Wertheim and Schauta, who in 1898 and 1902 described for the first time methodology of abdominal and vaginal hysterectomy, respectively. They paid attention to complication which existed after such procedures, i.e. urinary incontinence or retention, visceromotor disturbances with respect to bladder sensation (severe complaint in young females). Number of hypotheses were established to explain mechanisms of these ailments. In 1922 Latarjet and Rocher described for the first time probable causes of problems associated with bladder motion after hysterectomy. Several theses were put later on dealing with different damages of the bladder nerves, resulted from injury to inferior hypogastric plexuses and their subsidiary plexuses (visceral ramifications).

Oncologic surgical procedures in the pelvis carried out on changed tissues create a necessity of better, more precise mapping of the localization of structures of the autonomic nervous system in this particular region of the body. Special interest is paid to more precise and detailed localization of the hypogastric nerves and inferior hypogastric plexuses (IHP) — which are the most important representatives of the autonomic nervous system functioning in this body area, correlated with the peripheral somatic nervous system. There plexuses innervate sub- and partially retroperitoneal organs. Oncologic procedures requiring surgical removal of the whole organs (i.e. rectum, prostate, bladder etc.) or fragments of oncological changed tissues with oncologic margin of safety cause that a priori damages of numerous branches of IHP or even hypogastric nerves occur pretty common. Consequences of the lesions of these structures of the autonomic nervous system are lots of functional disturbances which may indirectly lead even to death, especially when one considers large radical excisions. Technical possibilities of the bladder prosthesis or reconstructive operations with use of large intestine, necessity of nerve preserving surgery associated with trends of maximal excision of oncological changed tissues requires deep knowledge of morphology, topography and course of IHP branches. A sort of “must-to”. Little iatrogenic lesions cause little postoperative complication (disturbances of micturition, defecation, sexual functions). Particularly important in the postoperative patient's recovery are pain syndromes associated with the lesions of the viscerosensory nerve fibers. Even partial recognition of morphology and topography of nervous structures probably enables development of better nerve-preserving techniques to minimalize after-effects of lesions. As a result the knowledge may improve patient's welfare, already mutilated [1–4]. Nowadays more and more often pain syndromes are treated using neurolysis — also in this case knowledge on the topography is essential.

The view on the autonomic nervous system from the ancient times until now

First reports on the structures of human autonomic nervous system are known from the times of Claudius Galen. In his elaboration, which had great influence on then existing views (until late medieval times) he described sympathetic trunks. Besides in their structure he distinguished the stellate ganglion located at the border between the cervical and thoracic portions. Probably he was able to differentiate also the thoracic ganglia. He presented quite interestingly his views of the function of sympathetic trunks, cause following his opinions they were able to transport the "motor power" (pneuma psychikon) from the brain to the organs [5].

The anatomical works which arose in 12 and 13th centuries — "Anatomia Magistri Nicolai" and "Anatomia Ricardii Anglici" were based mostly on Galen's reports and theses, not even trying to state something new. The texts described mostly the nerve fibers which united the spine and internal organs — considering that they carry motor and light touch impulses.

Andreas Vesalius, another excellent anatomist, father of modern anatomy, confirmed Galen's observation. Additionally he postulated that sympathetic trunks are branches of one of the cranial nerves. His essential opponent — Bartholomeo Eustachii — described thoracic ganglia of the sympathetic trunk with their branches joining them with peripheral nerves. Unfortunately his author copper plates have been published over 200 years after his death, so he did not affect European anatomy as much as did Vesalius. Both Eustachius (1552) as well as previously Stephanus (1545) distinguished vagus nerve as a separate structure — associated with autonomic nervous system.

The next researcher concerned with the studies on autonomic nervous system was Thomas Willis, famous for his description of the arterial system of the brain base. He described celiac ganglia and the superior mesenteric plexus, and most probably also the aortico-renal ganglion. Willis postulated that "vital force flows from the cerebellum toward viscera, while the celiac ganglia are its containers". He supposed that sympathetic fibers begin in the brain — what was a fault — however, what is interesting, as one of the first he established a hypothesis the migraine may be associated with vascular disturbances ("vasodilation"). In 1727 du Petit corrected Willis' observation about the origin of the sympathetic fibers and specified the key-role of white communicantes rami in the signaling process between the spinal cord and the paravertebral ganglia.

During next years Jean-Jacques Benigne Winslow, Danish anatomist introduced into anatomy a term "sympathetic trunk" (1732), and he proved the connections between the visceral plexuses.

Robert Whytt (1714–1766) dealt with neurophysiology of the autonomic nervous system, studying among others pupillary reflex. He studied also the influence of mechanical stretching of the intestinal wall by the meal and its affection on the peristalsis. As a conclusion it led to conception of the reflex arches within the autonomic system.

Marie Francois Xavier Bichat was the next researcher studying autonomic nervous system, although his findings were full of mistakes and did not clarify the problems. He suggested that paravertebral ganglia are independent on the preganglionic fibers. He distinguished the white and gray rami communicantes but did not know their role. He postulated that postganglionic fibers accompany mostly the vessels, while only few of them follow the viscera.

In 1843 Valentin found that some preganglionic fibers end in the ganglia, while some transit them.

The term "vegetative system" was created by Johann Cristian Reil (1759–1813). In his views he highlighted the influence of the system upon the "vital functions". He supposed however, what was not true, that these nerves conduct impulses only in disease, thus stimulating peripheral part of the autonomic nervous system.

Next anatomical discovery in the field of the nervous system was description of the non-myelinated nerve fibers by Robert Remak (1838) and myelinated by Bidder and Volkmann (1842).

Centers of autonomic nervous system were subject of profound studies of Brown-Sequard, who studied among others reflexes within this system. He proved that stimulation of the sympathetic nerve fibers leads to contraction of the vessel smooth muscles, whereas the stimulation of the chorda tympani causes dilatation of the vessels with simultaneous increase of salivation.

Gaskell left description of the autonomic nervous system ("The Involuntary Nervous System" 1916) — he postulated that communicanting branches are the centripetal — running toward the central nervous system; he recognized also that vagus nerves, sympathetic trunks and prevertebral ganglia constitute a consistent system. He noticed also that vagus nerves and sympathetic structures are antagonists relative each for other. He went further with his conclusions assuming the vagus nerves belong to anabolic system (preservation of energy and reserve building bloc) while sympathetic structures — form catabolic system (which mobilizes effort of the body exposed to the stress).

The terms used until now, i.e. autonomic system, pre- and postganglionic fibers, were introduced into anatomy and physiology by Langley (1889). During his experiments he discovered also phenomenon of blocking of the sympathetic ganglia by nicotine.

A researcher from Kraków who put special merit in the field of histogenetic studies on the autonomic system was the head of Anatomy Dept. of Jagiellonian University, prof. Zygmunt Szantroch (1894–1940). He dealt among others with the histogenesis of cardiac ganglia (PhD thesis), considering that ganglion cells together with the blood vessels originate from mesoderm. He postulated that parts of autonomic nervous system are not antagonists but the differ with receptors. In 1937 he started to collect data for modern textbook on anatomy of the nervous system (including the autonomic nervous system), unfortunately his premature tragic decease did not let him to finish his work. He remained a number of manuscripts.

Next milestones in the development of anatomical sciences were denoted in 20th and 21st centuries. More and more frequent are the procedures based on sympathectomies in the course of the treatment of vascular diseases and also methods associated with pain-transmission blockage in autonomic nervous system, especially in course of neoplasms (neurolysis). It was 21st and pelvic operations. Walsk, Mundy, and Enker gave the most known criteria for oncologic operations performed on pelvic organs (prostate and rectum) [6–8].

In 2015 in Kraków, it was held first World Conference on Neuromonitoring. The neuromonitoring within pelvic surgery is applied through adjustment of a specially configured sensor, which makes the course of autonomic fibres incorporated into surrounding tissues visible topographically, thus facilitating movements of the operator in the operative field in different branches of general and neurologic surgery. New accessories and techniques have been specially designed for pelvic and thyroid surgery to adjust their action to specific surgical conditions in these areas. Undoubtedly apart from the general surgery also proctologists, gynecologists and urologists may successfully use neuromonitoring during pelvic procedures, although application of this technique may be the domain of the future. Anyway deep anatomical knowledge of autonomic structures in described areas remains key value.

Surgical anatomy of pelvic autonomic nervous system

The nerve supply of pelvic viscera originates from the superior hypogastric plexus (SHP), sympathetic trunks, parasympathetic fibers of S2-S4 and sacral plexus. SHP is a continuation of the inferior mesenteric plexus which surrounds the lower portion of abdominal aorta, common iliac arteries and sacral promontory. Inferior mesenteric plexus is localized in the vicinity of the inferior mesenteric artery — it receives its sympathetic components from abdominal portions of sympathetic trunks. The source of the preganglionic parasympathetic fibers is located in the sacral parasympathetic nucleus (previously named intermedio-medial nucleus) found in the S2-S4 segments of the spinal cord. The axons of this nucleus follow the course of the hypogastric nerves. The plexus divides into two bands which reach the anterior aspect of abdominal aorta and join together at the level of its bifurcation into two common iliac arteries (sacral promontory), forming the SHP. Superior hypogastric plexus is a complex of nervous fibers located within the fat connective tissue, where nervous structures exists next to the vessels and organs. It is worth to stress that the plexus is a single structure which is placed in the median sagittal plane. Below promontory SHP divides into two fascicles of different width (4–7 mm wide) named presacral or hypogastric nerves. SHP extends laterally and anteriorly from the sacral pelvic foramina, covered by internal iliac vessels and retroperitoneal fatty connective tissue. In neighbors to sigmoid colon and rectum and continues as inferior hypogastric plexus (IHP).

Following particular authors SHP is an inferior division of the intermesenteric plexus. Hypogastric nerves originate from the lower end of the SHP, starting on the level or slightly below the sacral promontory. They reach the IHP along the postero-lateral pelvic border, placed almost parallel to internal iliac arteries. Minute connecting fibers, located between the right and the left hypogastric nerves form so called middle hypogastric nerve, although it is commonly difficult to distinguish it from the SHP. The above mentioned dense network of nerve fibers is placed between the parietal peritoneum and the pelvic fasciae. Hypogastric nerves join SHP and IHP (pelvic plexus). SHP joins with pelvic splanchnic nerves S2-S4, together with hypogastric nerves they are source of parasympathetic nerve fibers also for inferior mesenteric plexus. Subsidiary nerve plexuses are associated with the uterus, vagina, rectum and bladder — they originate mostly from the SHP. In example the uterus receives innervation from the utero-vaginal plexus — located next to so called transverse cervical ligament, which is a subject to doubt, lateral to uterine cervix (Frankenhäuser 1867). Nerve fibers spread in the uterus forming a specific plexus at the border between the endometrium and myometrium (Kranz 1959, Quinn 2003), and additional aggregations of fibers in the subserosal layer (Quinn 2003). The nerve supply of the endometrium remains unclear, although the cervix itself has a rich submucous innervation (Stjernholm *et al.* 1999, 2000).

The pelvic (IHP) plexus forms a triangle. Its superior border parallels the posterior aspect of the internal iliac artery. The posterior border (dorsal) is located next to the sacrum and gets afferents from ventral roots of the sacral spinal nerves. The inferior (caudal) border extends in between the origin of the ventral branch of S4 spinal nerve and the point of entry of the ureter through the posterior layer of the broad ligament. Out of three angles, the superior is identical with the beginning of the SHP, and contains the fibers of the unilateral hypogastric nerve. Antero-inferior angle is located at the above mentioned point of entry of the ureter (apex of SHP) and the postero-inferior angle is topographically associated with the point of adhesion to the ventral ramus of S4.

Numerous tryouts of operation techniques and complementary neoplasms treatment are elaborated over the years. Associated oncologic treatment (surgical and complementary: radio- and chemotherapy) affect unfavorably numerous pelvic organs. Common complication i.e. urinary incontinence or retention (bladder and urethral dysfunctions), "cleaving" sexual dysfunctions (lack of ejaculation, impotence, retrograde ejaculation, anorgasmia) appear as results of surgical procedures or other more or less aggressive treatments. Dysfunctions are common side effect of the lesions of autonomic nerves supplying organs. The attempts undertaken of possible wide resection of the lesions (preserving so called oncologic margin) and the degree of the autonomic nerve impairment is firmly associated with the experience of operator and his/hers manual skills. Undoubtedly a very helpful is anatomical knowledge, especially the knowledge on the topography of the pelvic fascial and nervous structures, which should be saved during dissection and has a direct influence on the occurrence of the disturbances.

Pelvic cavity is lined with the parietal layer of the pelvic fascia. It begins anteriorly from the pubic bone, laterally from the obturator internus fascia, covers the piriformis muscle together with the sacral plexus. At the level of the pelvic inlet (terminal line) it is continued by transversalis fascia and joins from below with the obturator fascia. Lower border is created by tendinous arch of the levator ani muscle. Particular portion of the parietal endopelvic fascia is the presacral fascia — layer of connective tissue which covers anterior surface of sacrum and protects presacral venous plexuses. Laterally the fascia becomes thinner and extends on the pelvic walls, forming among others so called lateral rectal ligaments (which contain middle rectal vessels and associated nerve plexuses). Damage to this area during a non-careful dissection may lead to numerous dysfunctions, mostly because of injury to IHP, located in the vicinity of mentioned structures.

Below tendinous arch of levator ani, parietal endopelvic fascia continues as fasciae which overlie the pelvic diaphragm and limit so called deep perineal space, previously named urogenital diaphragm. One can distinguish the superior and inferior diaphragmatic fasciae and similar for the formed urogenital diaphragm. The lamina of the superior diaphragmatic fascia continues in males as pubo-prostatic ligaments and pubo-vesical in females. Inferior lamina creates the medial limitation of the ischio-anal fossa.

Within the deep perineal space one can find transverse perineal muscles and pudendal nerves and vessels; in the females one can find greater vestibular glands and diaphragmatic portion of the vagina, and in the males: membranous portion of urethra and bulbo-urethral glands (of Cowper).

It is difficult to distinguish the visceral endopelvic fascia — it has a form of a thin layer which covers pelvic viscera (the bladder and the seminal vesicles in the male, upper portion of the vagina in the females). Posteriorly this fascia includes the rectum together with the mesorectum. The arrangement of the connective tissues structures allows to distinguish several compartments within the pelvis, filled with loose areolar tissue and fat:

- Paravesical space and retrovesical space (in the males)
- Vesico-uterine space and recto-vaginal together with the paracervical (in the females)
- Pararectal spaces
- Retrorectal space

Deep fasciae embrace pelvic organs: presacral fascia is a thick fragment of the parietal endopelvic fascia, covering the sacrum, the coccyx, nervous plexuses, median sacral artery and sacral veins (with no valves present inside) which unite with the system of internal vertebral veins. The presacral fascia slightly above the anorectal ring (S4) flexes anteriorly and inferiorly. It ascends the rectum joining with the rectal fascia and forms recto-sacral fascia (of Waldeyer). As a side note it should be mentioned that this name is used inappropriately, because William Waldeyer in his description of the pelvic fasciae did not distinguish the recto-sacral fascia at all.

Anteriorly the extraperitoneal portion of the rectum is separated from the vagina or from prostate and seminal vesicles by the visceral endopelvic fascia of Denovilliers. This is just the anterior parietal layer of endopelvic fascia which is named Denonvilliers fascia. Lateral portion of the endopelvic fascia covers bilaterally the area neighboring to obturator foramen and the iliac vessels.

In example: posterior and lateral walls of the rectum are associated with so called mesorectum, which thinking anatomically is not a mesentery, although developmentally originates from the common dorsal mesentery of the distal gut tube. The borders of the pseudo-mesentery are appointed by the visceral endopelvic fascia. It is limited by proper pelvic fascia and parietal endopelvic fascia, which covers sacrum and coccyx, and continues next onto the rectum (as Waldeyer's fascia). Anterior to the rectum visceral endopelvic fascia which covers the extraperitoneal portion of the rectum is named Denonvilliers fascia. Anterior to this fascia in the males we can find prostate together with seminal vesicles. In the females anterior to it one can find the vagina. During rectal excision in the course of rectal cancer the Denonvilliers fascia should remain on the resected organ, because it constitutes the border of so called safe dissection, which guarantees prostatic inviolability during rectal resection. Between the proper fascia of the rectum which covers mesorectum from behind, and the Waldeyer's fascia (covers sacrum) one can find so called "holy space" (avascular space).

Following Martinez-Pineiro [9] Dennonvilliers fascia is a sigle connective tissue membrane which separates the prostate from the rectum in the male. He supposes that it is impossible to distinguish the anterior and posterior laminae of this fascia, what we can find in anatomical textbooks. This is why the prostate is directly surrounded by pseudo-capsule, which adheres to the visceral fascia (prostatic fascia), which is separated from the rectum by the Denonvilliers fascia. Next to the base of the prostate part of the fascia runs anterior and separates the gland from the neurovascular bundles.

Mesorectum consists of:

- Fat tissue
- Connecting tissue elements
- Branches of the superior rectal artery with committant veins
- Autonomic nerve plexuses and their subsidiary branches
- Lymph nodes and vessels

The anterior surface of sacrum and so called presacral venous plexuses are covered with presacral fascia (parietal endopelvic fascia) — moro or less precisely at the level of first sacral vertebrae hypogastric nerves adhere to them, covered by bands of connective tissue. In the posterolateral part parietal endopelvic fascia covers the levator ani muscles. The hypogastric nerves descending down reach the mesorectum from lateral. More or less at the level S3, S4 the are reached by pelvic splanchnic nerves thus forming the pelvic (IHP) plexus. The parietal endopelvic fascia and the fascia oif mesorectum create a space which does not contain the vessels, and extends posteriorly, running from lateral. Within this space surgeons can operate organs rather safely. Lower part of the above mentioned space is occupied by the recto-sacral fascia, which originates from the lower presacral fascia and reaches the mesorectum about 3–5 cm above the anorectal junction. In the lateral portion the parietal endopelvic fascia divides into numerous bands of fibrous connective tissue. These bands in the posterolateral area adjoin the levator ani muscle, coming over the pudendal neurovascular bundle (the pudendal nerve and the internal pudendal vessels). The anterolateral bands cover elements of the pelvic plexus. Directly under the peritoneum on can see the origin of visceral branches to the rectum.

Branches of the plexus to the bladder, prostate, and seminal vesicles in the males arise from the antero-inferior portion of the plexus, which is positioned medial to the mesorectum of the lower rectum. Medial to the plexus the fasciae of mesorectum join with parietal endopelvic fascia, and the band established that way is commonly named lateral ligament (contains the middle rectal vessels).

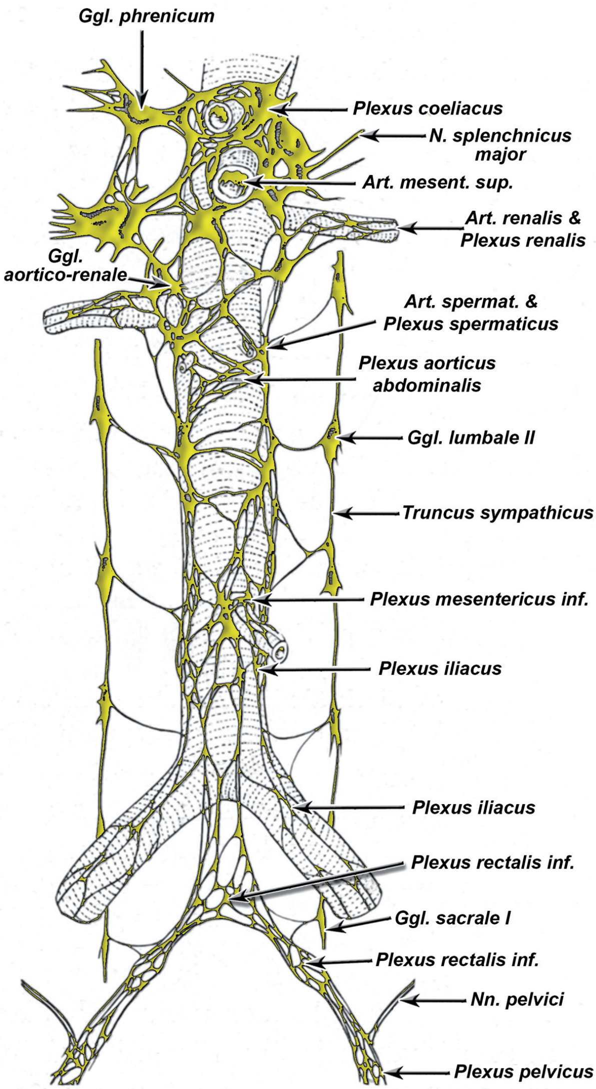


Fig. 1. Overview of the autonomic nervous system of the abdomen and the pelvis. Major nerve plexuses.

The topography of the structures which neighbor to the anterior wall of the rectum (with special respect to its lower portion) is really important. One can observe here special density of fascial tissues (collagen fibers, smooth muscles and elastin fibers) which has a form of urogenital septum (described for the first time by Denonvilliers in 1836). It is located next to the lowest portion of the rectovesical pouch, and reaches the inner aspect of the pelvic diaphragm. Denonvilliers fascia in the males gets on toward the seminal vesicles and the prostate, and to the back it reaches the mesorectum and its fasciae. Because of the shape of the fascial structures and the muscles forming the pelvic diaphragm, arrangement of the organs within the pelvis, rather densely packed, the shape of the mesorectum is similar to the cone with its base facing upwards.

The deep knowledge on the IHP topography has a fundamental meaning for the success during operations within the pelvic area and to avoid iatrogenic complication. It is this plexus which issues the fibers which communicate the processes of the intramural neurons, which supply the target organs. Its antero-medial aspect is the source of the nerve fibers which are expected to be the most vulnerable during incompetent dissection of the antero-lateral pelvic wall. In the males these are mainly the fibers located on the lateral and posterior surfaces of the seminal vesicles and the prostate. The run creating so called bundle of Walsh, between the rectum and the posterior aspect of the prostate and supply levator ani, rectum, prostate and the cavernous bodies of the penis. The above described bundle is covered by the Denonvilliers fascia and this is why it is mostly exposed to the trauma.

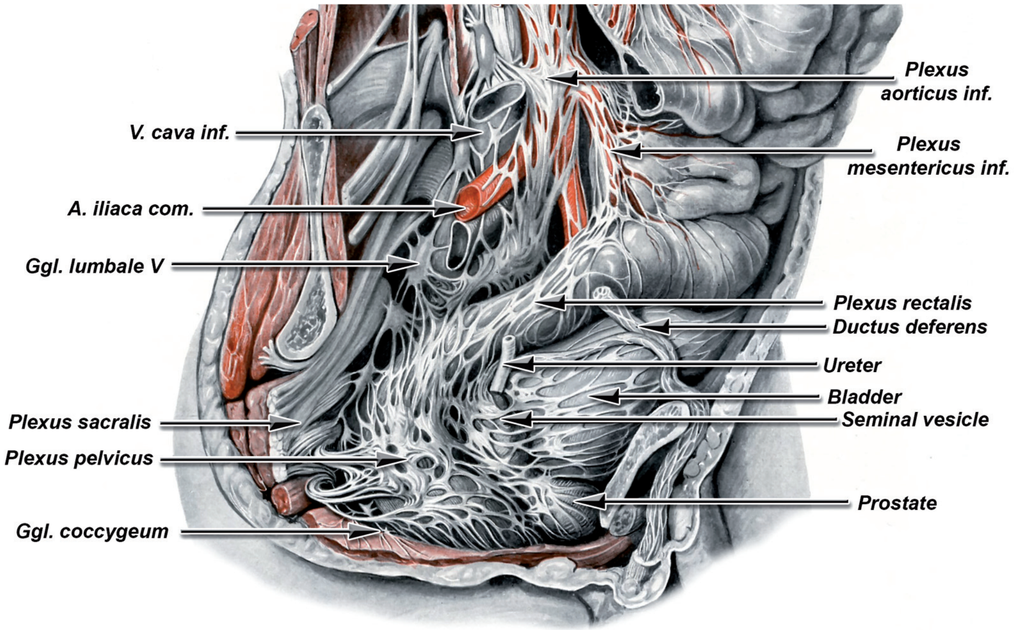


Fig. 2. Nerve plexuses of the pelvis.

It is worth to mention here that pelvic plexus has numerous centrifugal fibers and contains centrifugal neurons — which are the limbs of a large number of visceral reflexes. It is also reported that it contains also somatic fibers of the pudendal nerves, but their role remains obscure until the day.

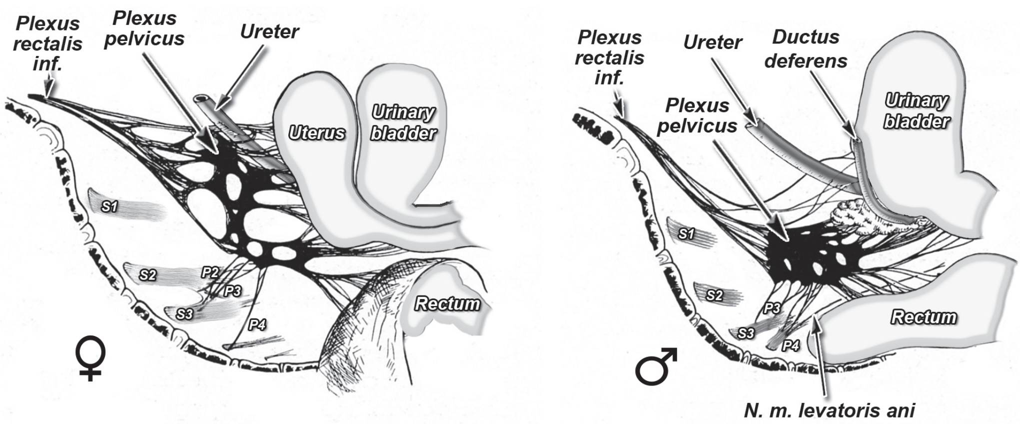


Fig. 3. Female and male IHP and efferent fibers.

Autonomic nervous system has a strong influence on the internal organs, thus contributing homeostasis. The name introduced for the first time by Langley — "autonomic" was stressing its independence from human will, its cortical centers. From another hand however this system is inseparably united with the somatic system, both anatomical and functionally.

Innervation of the urinary bladder

The urinary bladder is innervated by the fibers which originate from the pudendal nerves (somatic nerves) and from IHP (hypogastric and pelvic splanchnic nerves). The afferent fibers — which carry sensation from the wall of the bladder follow the autonomic fibers of the vesical plexus (subsidiary plexus of the IHP), and next follow the pelvic splanchnic and hypogastric nerves. Next they reach probably SHP, and enter the spinal cord. Particular fibers synapse in the sacral centers of the spinal cord (the center of reflexive micturition — S2-S5), while other fibers run to the centers located at the border between thoracic and lumbar portions (T11-L1). The remaining fibers use so called sacro-bulbar path to reach the brainstem, and next they reach cortical centers (the paracentral lobule, cingulate gyrus and the middle portion of the postcentral gyrus).

The efferent fibers arise from the pelvic splanchnic (parasympathetic) and hypogastric (sympathetic) nerves, also from the pudendal (somatic) nerves. The mentioned above pelvic splanchnic and hypogastric nerves adjoin the IHP and next through the vesical plexus run to the ganglion cells located in the wall of the bladder. They supply also the smooth muscle cell internal urethral sphincter and the bladder muscle emptying the bladder (the detrusor urinae muscle). The nerve fibers carried by the pudendal nerve enter the external urethral sphincter and the muscular components of the pelvic diaphragm and the deep perineal space.

Nerve supply of the male external and internal genital system

The afferent (sensory) innervation of the genitalia is mediated by somatic pudendal nerves. It is carried also through the sensory fibers which accompany the autonomic nerves (viscerosensory nerves) — mostly associated with the T10-S4 segments of the spinal cord.

The sympathetic efferent innervation of the male genitalia is mostly responsible for process of ejaculation. Axons of the lower lumbar segments of the spinal cord transit the sympathetic ganglia of the sympathetic trunks and form on the anterior surface of lower aorta the SHP. They synapse in its ganglia and already as postganglionic through the hypogastric nerves they reach the IHP. Next they run to target organs through the subsidiary plexuses to the prostate, ductus deferens, seminal vesicles and their efferent ductules [10].

Parasympathetic (efferent) innervation is responsible for penile erection. Sacral portion of the spinal cord (S2-S4 segments) gives rise to preganglionic fibers (axons of the sacral parasympathetic nucleus — previously called intermedio-medial nucleus), which next via pelvic splanchnic nerves go to the IHP. Much of these axons synapse in the ganglia of the plexus, and after it form the neurovascular bundle [8] together with the vessels located in the capsule of the prostate. Certain authors postulate that the further course of these fibers may be a subject of controversies [11, 12]. Some of the authors describe these fibers as easy to identify, located along the lateral (external) aspect of the seminal vesicles [2], while others stress that they do not form the common bundle and run rather in a disperse form, running toward the prostate on both sides of the urethra, reaching next the corpora cavernosa of the penis [12]. During lack of erection, in the resting position the caves (caverns) are almost empty, the walls relaxed, almost completely collapsed — and the vessels which supply them run tortuously (arteriae helicinae) and are obliterated. The blood flows through the artero-venous anastomoses passing by the cavernous bodies. The nerve stimulation causes relaxation of the muscles of the arteries and the extension of deep penile veins, what causes closing of the artero-venous anastomoses. The acetylcholine released on the nerve endings of the parasympathetic system [13] cause increase of the nitric oxide concentration, which relaxes the smooth muscles of the blood vessels. Subsequently the cavernous bodies fill with blood and the penile erection occurs. Simultaneously the blood filling the caves, following the Pascal's law generates a pressure which cause increase of the hydrostatic pressure, thus constricting the veins piercing the deep penile fascia and enable the maintenance of the erection.

During the emission which is the first phase of ejaculation, stimulation of the sympathetic system causes contraction of the smooth muscle of epididymis, seminal vesicles, and smooth muscle fibers of the prostatic capsule, thank to which the semen is transported to the urethra. Thanks to the contraction of the ischio-cavernous and the bulbo-spongiosus muscles it is possible to increase the ejaculation and at the same time contract the muscle of the bladder neck and urethra, what avoids the backflow of the semen to the bladder.

In case of spinal cord transection impotence practically does not exist if the lesion affect segments above the sacral region, while traumas of the pelvic splanchnic nerves or IHP causes lack of erection and ejaculation. Injuries to the hypogastric nerves or SHP cause disturbances with ejaculation, most frequently in the form of the retrograde ejaculation. If the lesion affects the innervation of the bladder sphincters or infero-posterior part of the bladder than during ejaculation it may come to regression of the semen back to the urinary bladder.

Outline of the autonomic innervation of the female genital organs

From anatomic standpoint the structure and paths of the nerve fibers which innervate the internal female genital organs are analogous to the males. The utero-vaginal plexus is a subsidiary plexus of the IHP which supplies the female internal genital organs. It isn't much known until now on the lesions and their symptoms. The main signs are: dyspareunia, dry vagina, anorgasmia, and changes in the vaginal discharge [14–17].

Practically it is difficult to prove that these symptoms are directly associated with the lesions of autonomic plexuses. The difficulties in the evaluation of the lesions after surgical procedures associated with the traumatization of the autonomic nerve fibers are results not only of very poor literature data but they also result from reluctance of undertaking and discussing this problem both by physicians and the patients [18]. From another hand however non-randomized studies may lead to sometimes curious conclusions, i.e. increase of the frequency of sexual intercourses undertaken after proctocolectomy in the course of ulcerous colitis, which is most probably associated with the improvement of the general well-being after operation which treated the main source of complaints.

Side effects of the lesions of the autonomic nervous system were observed during pelvic neurectomy in the course of treatment of pain caused by endometriosis, resulted from aware sectioning of the fibers of SHP. Between the symptoms dominated urinary retention, sudden episodes of micturition, dryness of vagina and anorgasmia.

Current outlines for structure and function of the autonomic nervous system

The functional and structural subdivision of the autonomic nervous system divides it into centers and peripheral structures of the sympathetic and parasympathetic nervous systems. Thus we distinguish the following:

- Centers (located within the central nervous system): placed in the cortex of the brain, diencephalon (interbrain) — hypothalamus, spinal cord
- Ganglia and plexuses included into the peripheral autonomic nervous system (plexuses have mostly mixed sympathetico-parasympathetic character)

Mentioned above cortical centers are localized mostly in the orbital gyri (the inferior surface of the frontal lobe), cingulate gyrus and insular cortex — particular anatomists define these regions as visceral brain or orbito-insulo-temporal cortex (so called secondary somatosensory area S II). The hypothalamus is a more important "subcortical" center, especially the posterior nucleus of hypothalamus — united with different cortical areas, including also thalamus. This nucleus contains thermoregulatory centers. It is this nucleus which gives rise to dorsal longitudinal fasciculus, which to some plays a role of coordinator of the activities of the sympathetic and parasympathetic nervous systems (i.e. nuclei of the cranial nerves with the sacral parasympathetic nucleus). Axons of the neural paths which begin in the hypothalamus (hypothalamo-hypophyseal and tubero-infundibular tracts) are special tracts passing neurohormones into anterior or posterior pituitary lobe.

In turn the medulla oblongata contains the vasoactive, respiratory, swallowing, emetic and cough centers. In the segments C2-T1 in the central intermediate gray substance of the spinal cord one can find the ciliospinal center; C8-L3 — pilloactive, finally in S2-S4, centers of erection, defecation and ejaculation.

In the spinal cord within the intermediate gray substance one can find the intermedio-lateral columns (nuclei). Accumulation of the cell bodies in these columns is so intensive that they produce additional gray matter horn — lateral horn. These horns are formed by the sympathetic neurons. Their axons exit from the intermedio-lateral nuclei, next they emerge from the spinal cord through the ventral roots of the spinal nerves. From the spinal nerves these axons emerge as sympathetic preganglionic which have a form of white rami communicantes, and reach the paravertebral ganglia of the sympathetic trunk. Here part of the axons terminate by synapsing, while the others transit: to the ganglia located within the sympathetic trunk higher or lower or to prevertebral ganglia — as splanchnic nerves. The postganglionic fibers from the prevertebral ganglia reach particular plexuses which innervate target organs. Axons of the cell bodies of paravertebral ganglia (sympathetic chain ganglia) reach the nearest spinal nerves, as gray rami communicantes — and next they distribute within the branches of these nerves and reach the blood vessels, the glands of the skin and erector pili muscles.

For the parasympathetic system we assume that centers are located in the brainstem and the spinal cord. The centers of the brainstem include the parasympathetic nuclei of the cranial nerves III, VII, IX, and X, while in segments S2-S4 one can find the sacral parasympathetic nucleus, previously named the intermedio-medial nucleus. Axons of the nuclei of parasympathetic nerves reach the adjacent parasympathetic ganglia: III — to ciliary ganglion; VII do pterygopalatine and submandibular ganglia; IX — to otic ganglion; X — to intramural ganglia), which supply their postganglionic fibers to target organs: glands, and smooth muscle cells of the head, neck and trunk, including also cardiac muscle.

Axons of the dorsal nucleus of vagus run mostly towards the plexuses of internal thoracic and abdominal organs, until the level of the border between the proximal 2/3 and the distal 1/3 of the transverse colon (so called point of Cannon-Bohm). This point is a natural border between the parasympathetic innervation of the viscera by vagus and sacral portion of the spinal cord. Preganglionic parasympathetic axons of the sacral parasympathetic nucleus follow ventral roots and spinal nerves, to reach finally the ventral rami. They separate from these last before entering the sacral plexus as pelvic splanchnic nerves. This nucleus is also a source of preganglionic fibers, which ascend into the inferior mesenteric plexus and next as postganglionic the fibers reach intramural and submucous ganglia of Meissner and Auerbach plexuses, where they synapse.

Peripheral part of the autonomic nervous system is composed also of the plexuses. The more important plexuses are the following:

- Cardiac
- Pulmonary
- Celiac
- Intermesenteric
- SHP
- IHP

Each of the plexuses gives off rich, mostly autonomic subsidiary plexuses, which spread along the vessels, and supply the target organs.

The axons of the intermedio-lateral nucleus (T12-L2) leave the spinal cord through ventral roots of the adjacent spinal nerves. The white rami communicantes which are continuation of the preganglionic sympathetic fibers, supply paravertebral ganglia (among others as interganglionic fibers all ganglia below L2). Part of these fibers terminate in the ganglia, others transit the ganglia to reach the prevertebral ganglia. Thus topographically one can associate postanglionic sympathetic fibers and (seemingly because of the transit) preganglionic fibers. Both create the intermesenteric and SHP located on the anterior aspect of the aorta.

The intermesenteric plexus is a continuation of the celiac plexus at the distance between the origin of the superior and the inferior mesenteric arteries (more precisely between the superior mesenteric and the inferior mesenteric ganglia) — part of its fibers is hidden in aortic adventitia forming paraaortal plexus. The intermesenteric plexus is reached by the splanchnic nerves, branches of the sympathetic and vagal trunks. It comprises the variable number of ganglia — i.e. inferior mesenteric, ovarian/testicular ganglia. The plexus issues subsidiary plexuses: inferior mesenteric and superior rectal, which follow the adjacent arteries. The plexus gives rise to certain number of the visceral rami:

- Renal
- Ovarian/testicular
- To inferior vena cava
- To the ureters
- Pancreatic

The intermesenteric plexus communicates to SHP through the sympathetic fibers which originate next to the beginning of the inferior mesenteric artery.

The SHP is located along the anterior aspect of the abdominal aorta and its bifurcation. Within the loose areolar tissue below the bifurcation one can find the sympathetic fibers, ganglia and lympatic vessels. Some authors postulate that afferent fibers of parasympathetic system also exists here. Particular researchers deny the existence of the SHP considering it to be only a continuation of the intermesenteric plexus [19]. After leaving the plexus these fibers run within paired hypogastric nerves, which parallel the common iliac vessels and the pelvic wall. They may comprise variable numbers of nerve fiber bundles [19].

Parasympathetic preganglionic fibers originate from the sacral parasympathetic nucleus (S2-S4 segments). They exit ventral roots, trunks and ventral rami of adjacent spinal nerves and form pelvic splanchnic nerves. They run along the pelvic wall, over the piriformis muscle, covered by parietal endopelvic fascia. Next they pierce it, to run between the anterior and posterior laminae of the visceral endopelvic fascia. After giving off the branches to the mesorectum, together with the hypogastric nerves, next to the lateral ligaments of the rectum they form IHP, located 4–10 c, above the anus (in the males: lateral and posterior to the seminal vesicles). The fibers of the plexus are located together with the vessels immediately below the parietal endopelvic fascia — and this is why it is so easy to injure them during careless dissection. The above described Denonvielliers fascia, which is located posterior to the plexus is a safe border of the anterior rectal mobilization [20].

The operations performed within the space of pelvis minor are still a technical advantage for a surgeon, and increasing frequency — or rather detection of neoplasms in this area results only in increasing the problem. Historically, surgical removal of fragments of the intestine together with the lesion lead to relatively quick recurrence — and only the TME technique (Total Mesorectal Excision) allowed to decrease the proportions of the recurrence. This technique is based mostly on almost perfect anatomical dissection within the interfascial spaces what lead to significant improvement of the results — unfortunately it was quickly denoted that dissection along the curve of the sacrum between the parietal (of Waldeyer) and visceral endopelvic fasciae, and anteriorly between the rectal fascia and Denonvilliers fascia, together with the closest possibly dissection from lateral and section of lateral rectal ligaments may cause bladder and sexual dysfunctions, i.e. bladder atony, problems with erection and episodes of retrograde ejaculation [21–24]. Described dysfunctions result from iatrogenic lesions of autonomic nerve structures of SHP and IHP, hypogastric nerves, or minute almost invisible during dissection nerve fibers placed within the peritoneum or Denonvielliers fascia. In 80' finally anatomy of pelvic nerves finally came to attention — with special respect to developmental issues, performing numerous studies on fetuses [25]. A dominating judgement appeared, that even gentle "blunt" dissection may cause tension and extension of delicate structures of autonomic nervous structures, and their damage as final effect. This is why attention was paid to operations performed "roughly". Walsh *et al.* [8] as first stated that preservation of the autonomic nervous structures during oncologic operations (of the rectum, sigmoid colon, prostate, bladder) has no influence on the radicality of the procedure and oncologic effects of the treatment performed. The attention was paid to the anatomy of the course of the nerve fibers, as well as the necessity of the ligation of the inferior mesenteric artery slightly further from its origin from the abdominal aorta, because of possible direct damage to the SHP. The removal of the hypogastric nerves and ligation of the rectal arteries far from the pelvic walls allowed the significant decrease of the complication rate [26–31].

The subsidiary plexuses of the IHP consist of the following:

- Middle and inferior rectal
- Vesical
- Prostatic
- Deferential
- Cavernous of penis
- Utero-vaginal

Middle and inferior rectal plexuses join the superior plexus (from the inferior mesenteric), and supply the middle and inferior portions of the rectum. These plexuses are supplied also by branches of the pudendal nerves. The vesical plexus gives off the superior and inferior vesical nerves to the fundus of the bladder, internal urethral sphincter, lower ureters, seminal vesicles and urethra in the males; in the females it joins the utero-vaginal plexus. Prostatic plexus arises from the inferior portion of the IHP, surrounding the infero-lateral surface of the prostate, supplying it. The derefential plexus accompanies the ductus deferens at the distance from the epididymis until the ampulla of the vas deferens and supplies the vas deferens and seminal vesicle (this plexus receives contributions from the prostatic and vesical plexuses and directly from the IHP). Cavernous plexuses of the penis are the anterior extensions of the prostatic plexus. They continue through the deep perineal space and reach the dorsal aspect of the penile root where they anastomose with the branches of the dorsal penile nerve. This junction gives rise to penile cavernous nerves which supply the cavernous bodies of the penis.

Utero-vaginal plexus is analogous to deferential and prostatic plexuses in the male. It comprises the cervical ganglion, connecting branches to the ovarian and vaginal plexuses and also rami which surround internal iliac arteries. Vaginal nerves give rise to strong cavernous nerves of clitoris.

A well-known fact states that nerves of the autonomic nervous system accompany the blood vessels (mostly arteries), what makes them vulnerable during vascular procedures [32], i.e. implantation of vascular prostheses. Numerous cases of complications are reported (impotence or retrograde ejaculation) after such procedures [33, 34]. Similar complications can be seen in the course of retroperitoneal lymphangiectomy — recommended in case of seminoma. The procedure is based on the removal of the lymphatic vessels and nodes located in the vicinity of the big vessels in this space, what may result in a lesion of intermesenteric and SHP plexuses [35–37].

All above presented information proves that good anatomical knowledge and its practical application may allow to avoid more serious complications, commonly decreasing quality of life of patients after surgical operations carried out in the pelvis.

The outline of the development of the autonomic nervous system

The autonomic nervous system develops in the third week of gestation, when the dorsally located to the notochord, ectoderm proliferates and thickens forming the neural plate. Development of the intermediate mesoderm causes elevation of the regions of ectoderm located along the long axis of the plate, thus forming the neural folds, which surround the neural groove. The apical fragments of neural folds are referred to as neural crests. Folds come closer each to other and join forming the neural tube, initially opened at both ends.

Around the fifth week the neuroblasts which arise from the thoracic neural crest cells migrate to the regions located on both sides of future spinal cord, back to the dorsal aorta. They migrate ventral to the foregut and disseminate along its anterior aspect, both cranially and caudally [38]. How do these cells reach the vicinity of the gut tube remains still unclear [39]. These cells form bilateral chains of ganglia united with cranio-caudal sequence of nerve fibers. Neuroblasts migrate both cervically and caudally thus elongating the trunks. Initially the ganglia preserve their segmental character, and later some of them fuse (i.e. in the cervical portion). First neuroblastic accumulations appear in the upper thoracic and lower lumbar segments of the spinal cord. Segmentation begins at the moment when fetus reaches the size of 1 mm and continues until the sixteenth week [40]. Another neuroblasts migrate anterior to the aorta forming periaortal thoracic and abdominal plexus — where the cells of celiac and mesenteric ganglia soon differentiate. Other sympathetic cells migrate to thoracic and abdominal viscera, mostly along the blood vessels, forming visceral sympathetic ganglia. Probably some of these neural crest cells form the chromaffin cells of adrenal medulla. Within the sympathetic trunks the axons of the intermediolateral nucleus reach the cells of the ganglia, synapse at the same level or follow the ganglion cells of higher or lower position. Some of the fibers through the trunks reach the periaortal plexuses. Around week 14 within the gray matter of the spinal cord one can observe the adult arrangement of the nerve cells — it means that i.e. motoneurons are located in the anterior horns, somato- and viscerosensory neurons are placed in posterior horns, while the autonomic neurons lie in the lateral intermediate gray substance. In the spinal cord the funiniculi (columns) of the cells extends trhroughout the whole length of the spine while in the brainstem they become separated forming collections in the form of cranial nerve nuclei.

During embryonic period visceral plexuses appear in the form of primitive collections of neuroblasts located along the course of large blood vessels. Later in their areas some ganglion cells differentiate, and the fibers which originate from the cells form the proper visceral plexuses.

In example celiac plexus arises from the cells located on the anterior and lateral walls of the aorta — in the embryonic period we do not observe ganglia, but one can obviously see connections from the vagal nerves which carry parasympathetic fibers to this plexus. From the fifth month of gestation within the celiac plexus the ganglia arise (celiac, superior mesenteric, and artico-renal). Around third-fourth month within the intermesenteric plexus we can see ganglia, among others the largest between them: the inferior mesenteric ganglion. More of less precisely in this period we can denote hypogastric nerves which carry the fibers to the IHP. During the above mentioned perios IHP is well differentiated, its structure resembles the adult structures — and one can distinguish subsidiary plexuses (vesical and utero-vaginal). The structures of SHP can also be seen at a very early stage of embryonic development [41].

Topography of the inferior hypogastric plexus (IHP)

There are few characteristic topographic landmarks relevant for the positioning of the inferior hypogastric plexus:

- Blood vessels
- Viscera

In terms of the vessels — IHP is placed along the posterior margin of the internal iliac artery. Its superior border is located predominantly about 10 mm from the artery. IHP covers the anterior aspect of sacrum — superior angle is usually crossed by the confluence of the veins forming the internal iliac vein. This angle is located about 5–15 mm from the point of confluence and about 26 mm from the ending fragment, where the internal iliac and the external iliac veins join together.

In terms of the viscera — the key structure which conditions the localization of the IHP is the ureter — usually not with the respect to the superior angle — because this angle is differently positioned with respect to the ureter, but in all cases the apex of the plexus is lying next to its contact (piercing place) with the posterior lamina of the broad ligament.

The fibers reaching the plexus are variable, both according to the source and number. Additionally the hypogastric nerves, which entwine with the IHP, at the postero-superior angle, join with the roots arising from the sacral spinal nerves and both sacral portions of the sympathetic trunks.

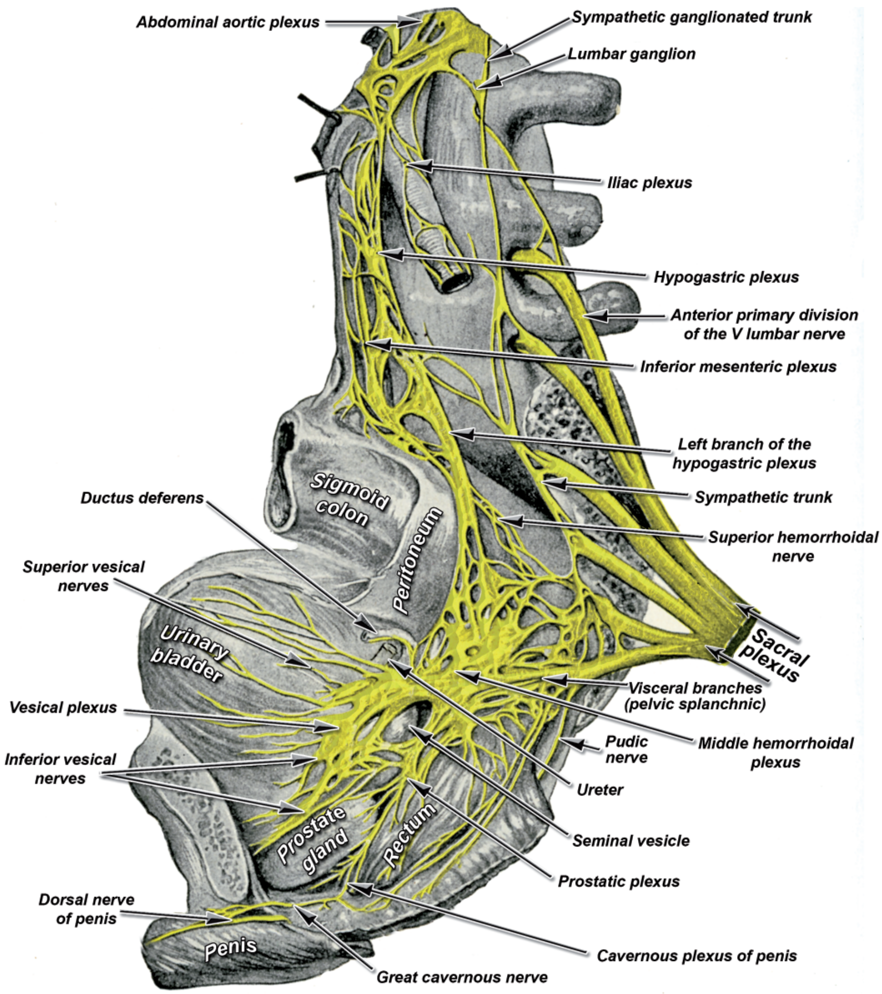
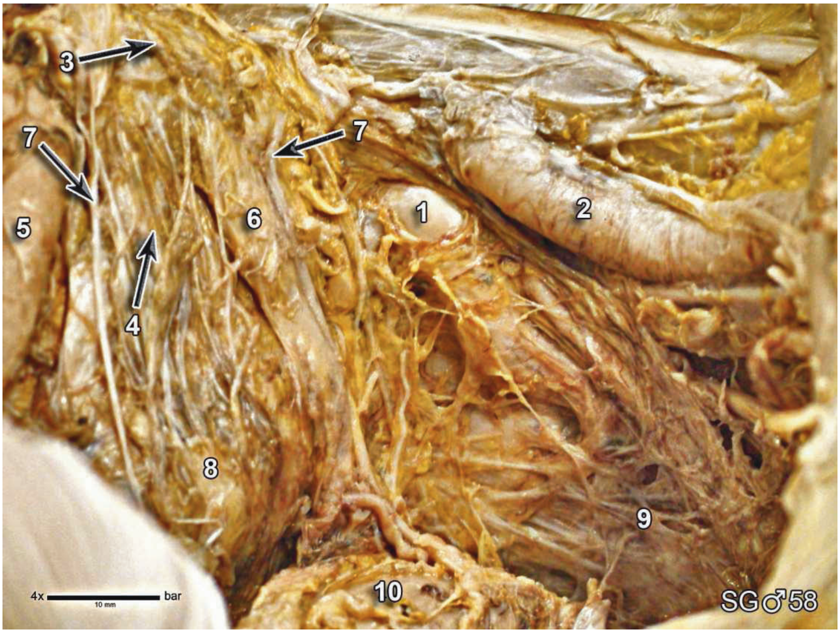


Fig. 4. IHP — connections to the sacral plexus.



1 — left internal iliac artery, 2 — left external iliac artery, 3 — SHP, 4 — right IHP, 5 — right common iliac vessels, 6 — median sacra vessels, 7 — hypogastric nerves, 8 — plate of right IHP, 9 — plate of the left IHP, 10 — rectum. *S.G. ♂ aged 58. Bar 4x.*

Fig. 5. Retrorectal space (rectum dissected and put aside). Inferior hypogastric plexuses.

The sources of the fibers to the IHP:

- From anterior rami of the sacral spinal nerves: 0% from S1, around 40% from S2, 20% from S5 and nearly 60% from S3 or S4
- From the sacral portion of the sympathetic trunk in about 30% — most frequently from sacral ganglia 2, 3, and 4
- Emerging fibers — efferent fibers from IHP reach the vesico-vaginal and recto-vaginal septum in the males, while in the females they create bundles which run lateral to the prostate.

Conflict of interest

None declared.

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